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**NASA TECHNICAL
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NASA TM X-52828

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**A SMALL DIFFERENTIABLE LIQUID SCINTILLATOR
NEUTRON SPECTROMETER**

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Cleveland, Ohio



TECHNICAL PAPER proposed for presentation at Sixteenth
Annual Meeting of the American Nuclear Society
Los Angeles, California, June 28 - July 2, 1970

FACILITY FORM 602	(ACCESSION NUMBER)	(THRU)
	11	1
	(PAGES)	(CODE)
	TMX-52828	14
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A SMALL DIFFERENTIABLE LIQUID SCINTILLATOR NEUTRON SPECTROMETER

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ABSTRACT

F-5729
A liquid scintillator neutron spectrometer utilizing pulse shape discrimination and a two parameter analyzer is described. The problems of determining a neutron spectrum from a measured proton recoil distribution are discussed. By using a small liquid scintillator about 1/2 inch in diameter by 1/2 inch long a good measurement of neutron spectra is obtained using the derivative of the proton recoil distribution. Measurements made with the 1/2 by 1/2 NE 218 scintillator for a 5 Ci PuBe source show general agreement with better resolution when compared with results for a 2 inch by 2 inch NE 213 scintillator utilizing the ORNL response matrix unfolding technique.

Measurements of the resolution of the 1/2 by 1/2 NE 218 scintillator give a value of 9% at 2.8 MeV and 5% at 14.7 MeV. These monoenergetic measurements for NE 218 show agreement with the light table for NE 213 measured at ORNL. A comparison is made between the measured and calculated leakage spectrum from a uranyl fluoride-water solution reactor. The 1/2 by 1/2 NE 218 measurements show general agreement with the calculation. The resolution of NE 218 is sufficiently good to indicate the effects of scattering resonances in oxygen; valleys at 0.5 MeV and 1 MeV are present in both the measured and calculated spectra.

INTRODUCTION

The use of organic scintillators to measure neutron spectra in the energy range of 0.5 to 15 MeV has been developed into a valuable tool for reactor shielding measurements. The work at Oak Ridge^{1, 2, 3} in

which a response matrix for a 2 by 2-inch NE 213 scintillator is used to unfold the measured proton recoil distribution has been particularly successful. However, the response matrix method has the present disadvantage of a lack of versatility. The 2 by 2-inch NE 213 scintillator is sensitive to the incident neutron angular distribution and must be used in an orientation that corresponds to its measured and calculated response; furthermore, it has too high an efficiency for some applications. For liquid scintillators significantly smaller than that used in reference 1, multiple scattering effects are minimized so that it may be possible to obtain accurate spectra by simply using the derivative of the measured proton recoil distribution rather than a response matrix. In addition because of its compactness, a small scintillator mounted on a 1-inch photomultiplier tube could be used to measure fast reactor central fluxes or total fluxes in a shield.

Direct differentiation has been widely used with small stilbene^{4, 5} crystals and corrections applied to account for deviations of the measured proton recoil distribution from an ideal distribution. Corrections are required because of the following interactions in the scintillator spectrometer:

1. Neutron multiple scattering
2. Proton leakage
3. Carbon recoils and alpha particle production

In the case of stilbene light output anisotropy is an additional complication that is difficult to take into account. For liquid scintillators, light output is isotropic and this problem does not exist. By using a small liquid scintillator about 1/2 inch in diameter by 1/2 inch long, neutron multiple scattering is minimized for the fission spectrum energy range and proton leakage is a small effect below about 7 MeV. In addition, by making full use of pulse shape discrimination with a two parameter analyzer, alpha particle pulses can be recognized and protons that lose only part of their energy in the scintillator also form a distinct group. Therefore the deviations from the ideal proton recoil spectrum

caused by proton leakage can be detected and alpha particle pulses eliminated. The amount of effort necessary to define errors in corrections to neutrons spectra determined by the present method should depend on the accuracy of measuring proton recoil spectra prior to direct differentiation.

In the present work a ^{5}Ci PuBe source spectra and a solution reactor leakage spectra have been measured using a 1/2 inch by 1/2 inch liquid scintillator containing NE 218. The superior pulse shape characteristics and light output of NE 218 is discussed in reference 6. The analysis of the proton recoil spectrum that was employed is that for single scattered neutrons and no proton leakage as given in reference 5.

SPECTROMETER

A block diagram of the spectrometer is shown in figure 1 along with the photomultiplier tube base circuit. A linear pulse is taken from the 10 dynode of the photomultiplier tube, amplified and sent to one side of the analyzer. A pulse whose amplitude depends strongly on the shape of the linear pulse is taken from the 12 dynode. Commercially available amplifiers and analyzer are used. The Owens type pulse shape circuit utilizing space charge saturation is built into the dynode chain of the RCA 8575 tube. The two diodes shown in the circuit eliminate the unwanted large negative part of the pulse obtained from this type of circuit. With 2000 volts across the tube dynode chain it is possible to separate neutron and gamma ray interactions down to 20 KeV electron energy which corresponds to a proton energy of 200 KeV. This separation has been achieved in a 10:1 gamma to neutron field.

The spectrometer is calibrated using a Na^{22} gamma ray source. A calibration curve is shown in figure 2. Also shown in the figure is a Co^{60} curve which shows that the two Co^{60} gamma ray compton edges are resolved. The resolution of the 1/2 inch by 1/2 inch spectrometer is about 9% at the calibration energy of 1.12 MeV beta particle energy which corresponds to the half height of the Na^{22} edge. The light table

published in reference 1 is used to relate this calibration to proton energy. A monoenergetic neutron source measurement at 2.8 MeV and 14.7 MeV using this calibration is in good agreement with the data in reference 1.

SPECTRUM MEASUREMENTS

Measurements have been made of a 5 Ci PuBe source using the 1/2 inch by 1/2 inch NE 218 scintillator and also the 2 inch by 2 inch NE 213 scintillator. In addition measurements have been made of a solution reactor leakage spectrum using the 1/2 inch by 1/2 inch scintillator. The measurements were made in the NASA Zero Power Reactor Room which is a 20'x32'x20' underground concrete room. The reactor core used was cylindrical 12 inches in diameter and 11 inches high and consisted of a UO_2F_2 water solution contained by an aluminum vessel which is held midway between the floor and ceiling of the room by a steel grating. Room background was obtained using a 12 inch by 1 inch by 30 inches long conical paraffin shadow cone. In the case of the source a 3 inch diameter by 30 inches long cylindrical shadow cone was used. The spectrometer was placed 3.5 feet from the curved surface of the sources. Counting times varied from 1/2 to 4 hours for the various amplifier gain settings used.

RESULTS AND DISCUSSION

The spectra obtained from the 5 Ci PuBe source is shown in figure 3. There is good general agreement between the two measurements. The 1/2 by 1/2 data shows deeper valleys in the spectra which can be explained by the superior resolution of this scintillator. The integral of the two spectra above 5.5 MeV shows the 1/2 by 1/2 data to be about 10% lower. This difference can be due to proton leakage from the small scintillator but is difficult to assign because of the inherent uncertainty in the energy calibration and counting statistics of the measurements at high energies.

The solution reactor spectra and proton recoil distribution are rather smooth and featureless above about 5 MeV, however the resolution of the spectrometer is good enough to show some of the low energy structure in the spectrum due to oxygen resonances. The low energy part of the measured proton recoil distribution for two gain settings is shown in figure 4. The changes in slope at neutron energies of 0.5 and 1 MeV indicated in the figure correspond to valleys in the neutron spectra.

The solution reactor leakage spectrum was measured using four amplifier gain settings to cover the range from 350 KeV to 15 MeV neutron energy. The neutron spectrum is shown in figure 5 and the shape of the measured spectrum is compared with a 50 group P_1S_4 transport calculation. The measurement is in general agreement with the calculation but has a slightly steeper slope above 7 MeV. This may be expected as there is a small amount of proton leakage from the scintillator volume. The valleys at 0.5 MeV and at 1 MeV due to scattering resonances in oxygen are present in both the measurement and the transport calculation.

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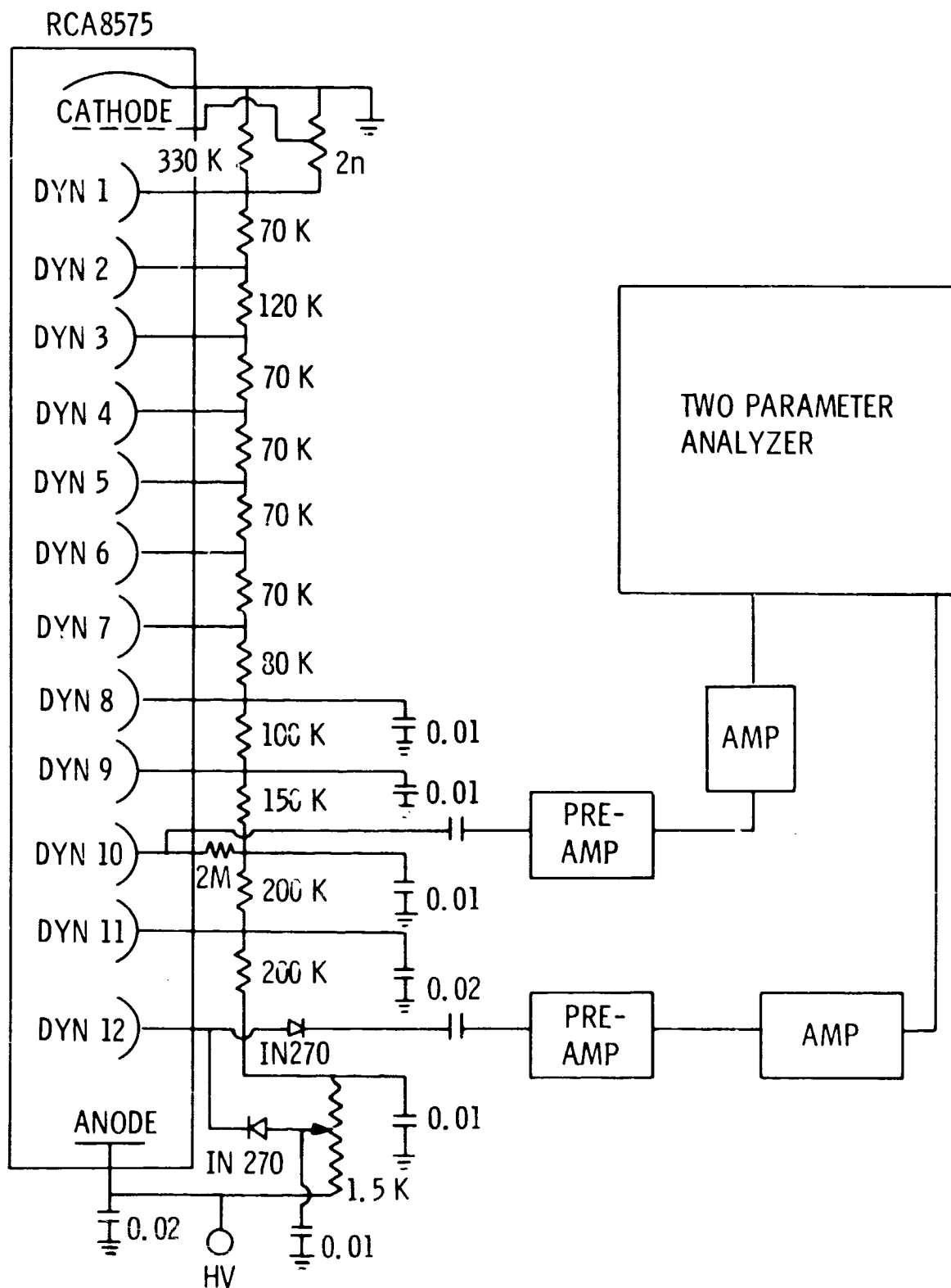


Figure 1. - Spectrometer block diagram and photomultiplier tube base circuit.

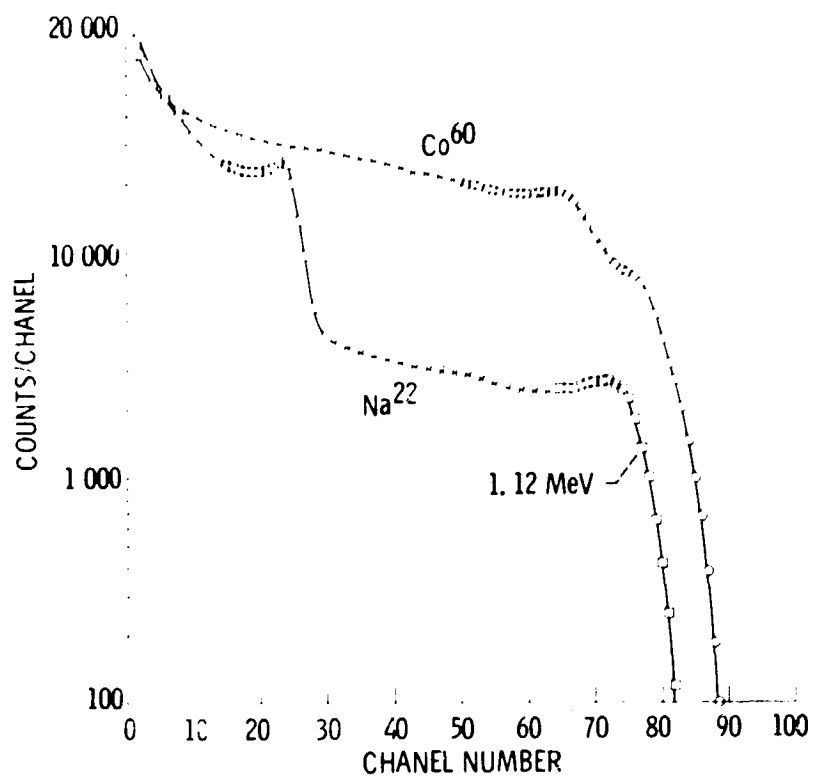


Figure 2. - 1/2 by 1/2 inch NE 218 calibration curves.

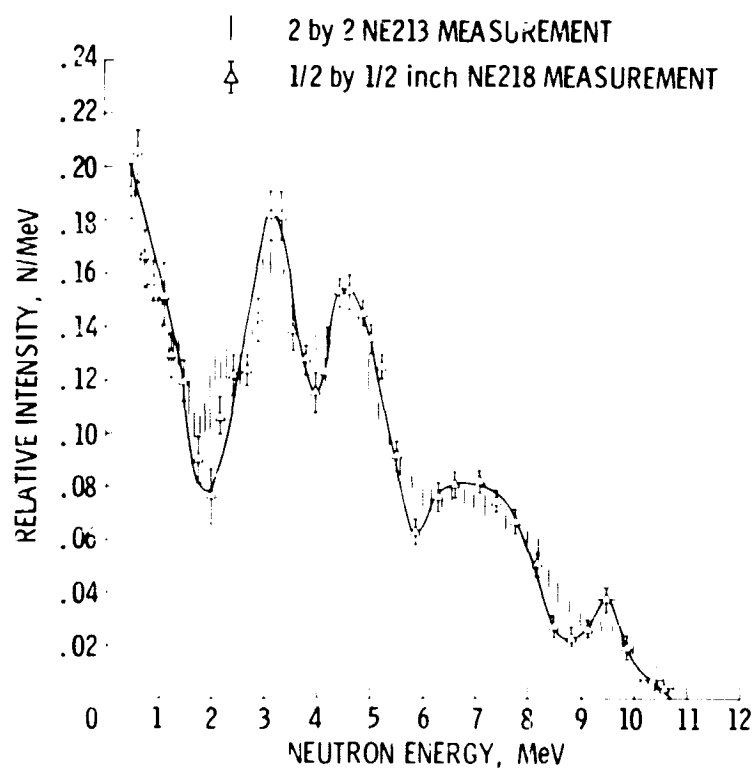


Figure 3. - 5 Ci PuBe neutron spectra.

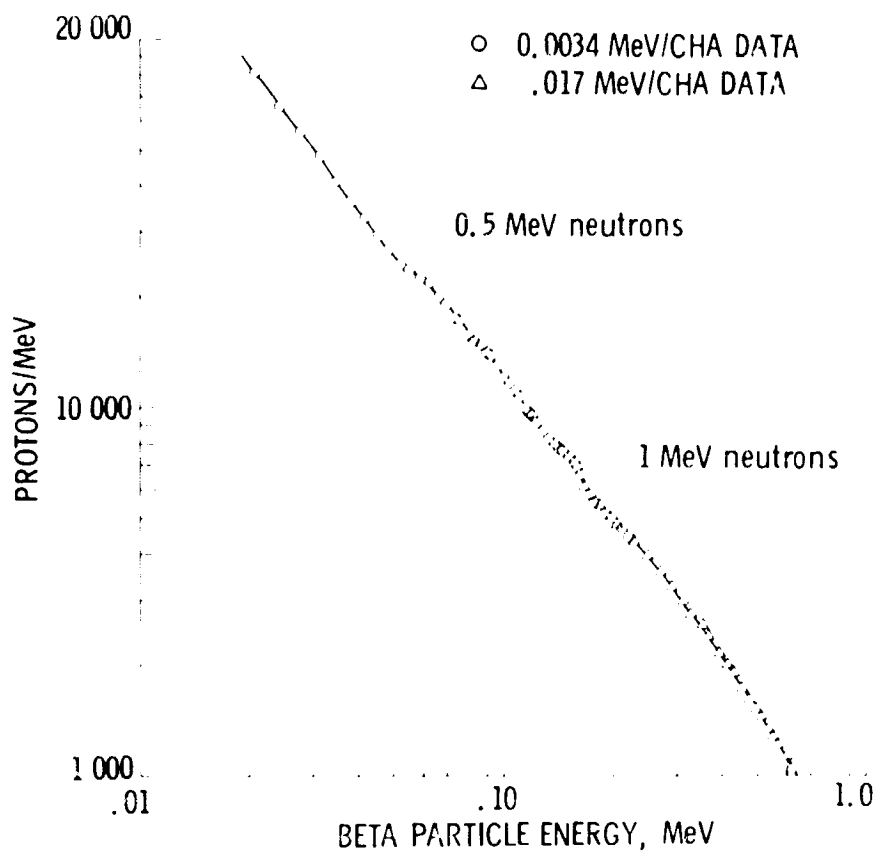


Figure 4. - Proton recoil distribution solution reactor leakage spectrum.

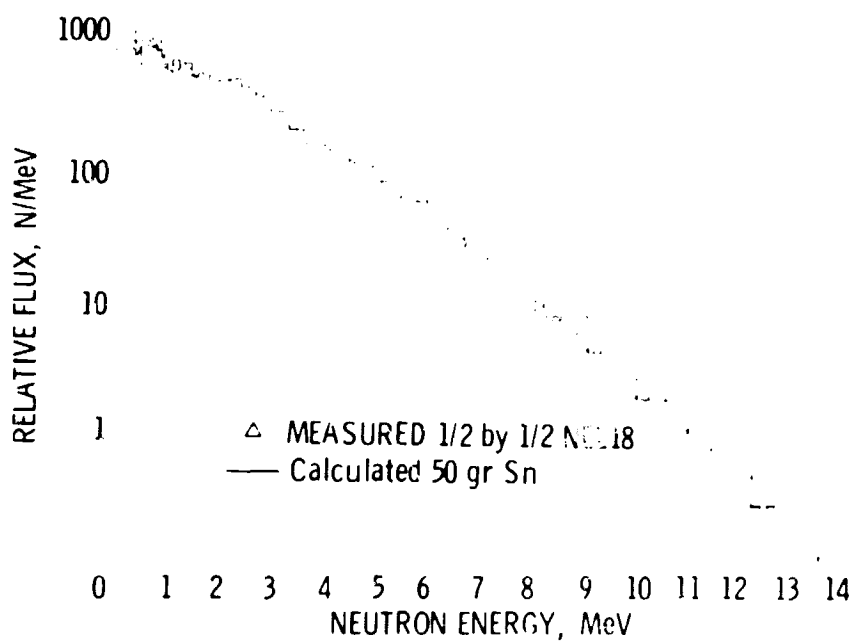


Figure 5. - Solution reactor leakage spectrum.